SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-90/7

Final Report

THE EFFECTS OF THE ALL-RED CLEARANCE INTERVAL ON INTERSECTION ACCIDENT RATES IN INDIANA

Brian A. Roper
Jon D. Fricker
Kumares C. Sinha
Robert E. Montgomery

PURDUE UNIVERSITY

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Final Report

TO:	Vincent P. Drnevich, Director Joint Highway Research Project	April 26, 1990 Revised June 3, 1992 Project: C-36-17QQ
FROM:	Kumares C. Sinha, Research Engineer Joint Highway Research Project	File: 8-4-43

Attached is the revised Final Report on the second part of the HPR Part II study, "An Evaluation of Leading Versus Lagging Left-Turn Signal Phasing and All-Red Clearance Intervals." This report presents the research findings on all-red clearance intervals. Statistical tests indicated that all-red clearance intervals did not cause a reduction in accident rates at the intersections studied in Indiana. The research for this report was conducted by Brian Roper under direction provided by Profs. Jon D. Fricker, Robert Montgomery and me.

The revisions reflect the helpful comments of the draft report's reviewers. Most notable is the complete revision of Table 8.

This report is forwarded for acceptance by the INDOT and FHWA as fulfillment of the objectives of the project.

Respectfully submitted,

K. C. Sinha /rrp

K. C. Sinha
Research Engineer

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THE EFFECTS OF THE ALL-RED CLEARANCE INTERVAL ON INTERSECTION ACCIDENT RATES IN INDIANA

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Project No.: C-36-17QQ
File: 8-4-43

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station

Purdue University
in cooperation with the

Indiana Department of Transportation

and the

U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, Indiana

April 26, 1990
Revised June 3, 1992

TECHNICAL SUMMARY

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THE EFFECTS OF THE ALL-RED CLEARANCE INTERVAL ON INTERSECTION ACCIDENT RATES IN INDIANA

Brian Roper, Jon Fricker, Kumares Sinha & Robert Montgomery
FHWA/JHRP/IN-90/7

April 26, 1990, Revised June 3, 1992

Background

The use of the all-red clearance interval at signalized intersections has been a subject of intense debate among traffic engineers for over a decade. Although several studies have documented the all-red interval's ability to reduce accidents within two years of its installation, no published studies have addressed what happens beyond that time. For the present study both the short-term and long-term effects of the all-red interval on accident rates in Indiana were evaluated using statistical analysis of Indiana accident records for the years 1981 to 1987.

Results and Conclusions

Seven years of accident data were obtained to assess the accident rates for two randomly sampled groups of intersections. One group was treated with the all-red interval and the other was not. Each comparison group intersection was paired with one in the treated group, based on entering volume, angle of intersect, and approach speed limits. From traffic volume counts, the estimated exposure rate at each intersection was calculated. Rates for four different accident types (left turn, rear end, right turn, and right turn angle) and for the total number of accidents were determined. Several statistical methods were used to analyze the resulting accident rates. In addition, three of the early all-red interval accident studies were reproduced with Indiana data to see if the results would be the same.

The results from the statistical analysis contradict those of previous studies. The Wilcoxon Signed Rank Test yielded few differences between the treatment and comparison intersection accident rates. The Student's t-test yielded a difference in right angle accident rates at the treated intersections one-year before and after the installation of the all-red interval. All other Student's t-test comparisons resulted in no difference. The Chi-square test results showed few differences in accident rates over four years. Thus, the all-red clearance interval did not cause a reduction in accident rates at the intersections studied in Indiana. Possible explanations and suggestions for further research are presented.

Contact

For more detailed information, contact Jon D. Fricker, School of Civil Engineering, Purdue University, W. Lafayette, Indiana 47907 (Tel: 317-494-2205).

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-90/7		

4. Title and Subtitle	5. Report Date
THE EFFECTS OF THE ALL-RED CLEARANCE INTERVAL ON INTERSECTION ACCIDENT RATES IN INDIANA	April 26, 1990 Revised June 3, 1992
	6. Performing Organization Code
7. Author(s) Brian A. Roper, Jon D. Fricker, Kumares C. Sinha and Robert E. Montgomery	8. Performing Organization Report No. JHRP-90/7
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907	10. Work Unit No. 11. Contract or Grant No. Indiana-HPR-2015
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration on HPR Part II Study.

16. Abstract

The research reported is an evaluation of all-red clearance intervals as the second phase of a project involving traffic signal operation. The first phase of the project dealt with leading versus lagging left turn signal phasing. The study analyzed both the short-term and long-term effects of all-red interval on accident rates in Indiana using accident records for the years 1981 to 1987. The results contradict those of previous studies. Statistical tests indicated that all-red clearance intervals did not cause a reduction in accident rates at the intersections studied in Indiana.

17. Key Words	18. Distribution Statement
All-Red Clearance Interval; Accident Rate; Traffic Signal; Safety	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENTS

The help provided by Messrs. Carl Tuttle and Ed Ratulowski, the project advisors from the Indiana Department of Transportation and the Federal Highway Administration Divisional Office, respectively, is gratefully acknowledged. The authors are also grateful to Mr. David P. Moffett for writing necessary software and to Dr. Joseph Hummer and Ms. Lara Belcher for help in field data collection.

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CHAPTER 1 - INTRODUCTION

General

The pros and cons of including an all-red clearance interval in a traffic signal cycle have long been debated by traffic engineers. An all-red interval consists of one to two seconds of red ball displayed after the yellow interval to clear the intersection before releasing the opposing movement. The expected advantage from this action is an increase in safety at the intersection due to a reduction in the opportunities for conflict (i.e. accidents and near-misses.) By devoting four or more seconds per cycle to the all-red interval, however, intersection green time and capacity are inherently reduced. Traffic engineers are not in agreement on the long-term safety effects of the all-red interval and how widely it should be applied. Some advocate that the all-red interval should be used at all intersections to reduce accidents, regardless of warrant. Others counter that the addition of the all-red interval should be specifically warranted and implemented sparingly. In recent years, traffic engineers have begun to indiscriminately add the all-red interval to their signal timings without regard to whether it is necessary. As litigation against traffic engineers continues to grow, they become more reluctant to withdraw the all-red interval once it has been implemented.

Research has been carried out on a number of questions concerning the all-red clearance interval. Although several studies have shown a reduction in accidents or accident rates within one year of the implementation of the all-red interval, researchers have not addressed the topic of reductions over a longer period of time. Thus, many traffic engineers implement the all-red interval blindly, without knowing if it will continue to reduce accidents long after it has been implemented. The intent of the present research was to examine both the short-term and long-term effects of the all-red interval on accident rates.

With the solution to the question of all-red interval accident rate reduction, gains can be made regardless of the findings. If it is determined that the all-red interval reduces accident rates, then the potential for accident savings certainly exists. On the other hand, a contradictory finding can also yield significant savings. The potential for a decrease in delay, fuel, and pollution costs certainly exists if the all-red interval is deemed ineffective and subsequently removed.

Purpose and Scope

The primary purpose of the research described in this document was to assess the short-term and long-term accident rate reduction effects of the all-red clearance interval on accident rates in Indiana. A secondary purpose of the research was to increase the body of knowledge regarding the all-red interval. Although previous studies have addressed the short-term accident rate reduction, none have looked beyond the first year of all-red interval implementation. Additionally, these studies did not assign a control group to assess reductions in the accident rate which were not linked to the all-red interval. These approaches provide a better picture of the true abilities of the all-red interval to reduce accidents.

The scope of the research was limited in a number of ways. First, locational differences were avoided by restricting intersection locations to Indiana. Second, uncommon intersection configurations such as five-leg or offset approaches were not included to avoid confounding the nature of the accidents. Third, accident data availability confined the study years to the period 1981-1987. Fourth, limited intersection counts and all-red interval data reduced the sample size to twenty-five intersections. Although these factors resulted in a smaller sample size than desired, the results of the study were not adversely affected.

Report Outline

The major area of potential concern relative to the all-red clearance interval which was explored in this research was short-term and long-term accident rate reduction. This topic and others are addressed in Chapter 2, which contains a review of relevant past published research findings. Intersection and accident data were collected from the Indiana Department of Transportation and the Indiana State Police. The methodology for this effort as well as for the statistical and literature tests performed on the data are presented in Chapter 3. The results of these tests are presented and analyzed in Chapter 4. The conclusions of the all-red clearance interval study and suggestions for future research comprise Chapter 5.

CHAPTER 2 - LITERATURE REVIEW

Introduction

A summary of the literature concerning all-red clearance intervals is presented in this chapter. The literature relating the all-red interval to intersection safety is presented first, followed by timing, professional opinion, and driver behavior. The review of the literature helped identify areas which have been previously researched.

Safety

Several studies in the past thirty years have claimed that all-red clearance interval in the signal cycle improved safety during a given time period. A brief summary of each published study follows.

Newby [1961] studied periods of two years before and two years after the all-red interval was added at twelve intersections in England. An examination of the number and type of injury accidents showed a marked decrease in two-vehicle accidents relative to area trends. This effect was attributed to the introduction of the all-red interval.

Wilson [1965] studied the City of Portland's removal of the all-red interval from 20 of its 525 signalized intersections. Total accidents for one-year before and after periods were examined. For the three intersections in the central business district, where volume was high and speeds were low, the number of accidents decreased. Locations with higher volumes and speeds than the central business district experienced an increase in the number of accidents. The same was true for high speed, isolated intersections.

Conradson and Bunker [1972] evaluated the effects of adding all-red clearance intervals at 17 intersections. These locations were selected for their high speed approach, poor visibility, and/or right angle accident pattern. Different types of accidents for one year before and after periods were examined. Total accidents were reduced from 429 to 385, due mainly to the reduction in right angle accidents (from 141 to 75). Rear end accidents increased from 116 to 158 while left turn accidents remained unchanged.

The City of Los Angeles [1973] studied the effects of adding all-red clearance intervals at 36 high volume, high accident locations. Different types of accidents for before and after periods ranging from 12 to 30 months were examined. Total accidents were reduced, due mainly to the reduction in right-angle accidents. Left turn accidents decreased and rear end accidents increased, but not significantly. They also concluded that all-red control is seldom economically justified.

Hoppe [1977] conducted a before and after study of all-red intervals at 148 locations in Los Angeles. Different types of accidents for before and after periods ranging from one to three years were examined. Total accidents were reduced, due mainly to the reduction in right-angle accidents. Left turn accidents showed no significant reduction.

Benioff et al. [1980] performed the most comprehensive study of the addition of an all-red interval to date. This study was the first to use accident rates instead of accidents as a primary measure of safety. For

45 locations, different types of accidents for a three-year before period and a one-year after period were examined. The total accident rate decreased, due mainly to the reduction of the right-angle accident rate. Rear end accident rates decreased and approach turn accident rates increased, but not significantly.

In addition to these studies, the ITE Technical Council Committee 4A-16 [1985] noted a Canadian example. The Regional Municipality of Hamilton-Wentworth, Ontario, experienced a 21 percent reduction in right angle accidents in the first year after including all-red clearance intervals at all intersections.

Benioff et al. [1980] concluded that intersections with a right angle accident rate greater than 0.8 right angle accidents per million entering vehicles should be considered for addition of an all-red interval. Similarly, Bissell and Warren [1981] suggested an all-red clearance interval if the number of right angle accidents exceeds 1.0 per million entering vehicles. It can be noted from the preceding sections that none of the studies used a comparison group to measure the all-red interval's success relative to non-all-red intersections. In addition, these studies did not attempt a long-term analysis of the accident history after the all-red interval's installation.

Timing

Parsonson and Santiago [1980] brought the debate over the timing of the clearance interval to center stage. They asserted that the inadequacy of clearance interval timing exposed the profession to greater liability. Bissell and Warren [1981] claimed that the yellow indication should not be used to clear the intersection.

Frantzeskakis [1984] proposed a methodology for estimating signal change intervals based on the West German practice. He stated that the U.S. signal timing methods are inconsistently safe. The proposed method considered the actual critical conflicting points between vehicles and pedestrians.

Stein [1986] reviewed the basic policies for traffic signal clearance interval timing, the current timing practices based on these policies, and their implications for the safety of motorists and pedestrians. Among other things, he concluded that not all traffic signals have clearance interval timing specific to the intersection's characteristics.

Jourdain [1986] evaluated all-red interval timing practices of Britain and the United States. She proposed other methods to determine the length of the all-red interval for certain speed conditions.

Hulscher [1984] concluded that, in Australia, current all-red interval timings are not critical due to the effect of driver adaptation. He developed a simple set of intergreen (all-red interval) timing relations for practical use.

Professional Opinion

Hoppe [1977] surveyed 35 transportation agencies about the all-red interval. Many of the agencies acknowledged that the all-red interval was being used as a method to reduce accident frequency. The agencies also noted that little or no data was available to substantiate its use.

Benioff et al. [1980] surveyed 232 city, county, and state transportation agencies about the all-red clearance interval. Ninety percent of the agencies responding to the questionnaire used the all-red interval. But there was no single warrant or type of warrant described as being in common usage. More tellingly, 75 percent of the agencies had not studied the effects of the all-red clearance interval on traffic operations or accidents.

Butler [1983] contended that an all-red clearance interval must follow every yellow interval if the traffic engineer is to meet the requirements of reasonableness in providing change intervals.

The ITE Technical Council Committee 4A-16 [1985] noted that few topics can so easily generate strong feelings among traffic engineers as the use of the all-red clearance interval. When it came to a final vote, five of the members strongly supported a recommendation that red clearance intervals be used after every yellow and four members felt that such mandatory use of red clearance intervals was possibly justified. The remaining two members and some commenters were adamant in their opposition to the recommendation, believing instead that red clearance intervals should be used only in certain instances. They believed that the all-red interval excessively reduces intersection capacity relative to their safety benefits.

Driver Behavior

The FHWA [1988] stated that the all-red interval be "of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released."

Benioff et al. [1980] determined that drivers do not have a significantly greater tendency to enter the intersection on a red signal when an all-red clearance interval is added.

Ryan and Davis [1982] investigated the extension of the amber interval into the all-red interval at 10 intersections in New England. They concluded that more drivers ran the red light at intersections that had the all-red clearance interval than at intersections that did not have it.

Wortman and Matthias [1983] studied the effect of the all-red interval on driver behavior at 6 intersections in Arizona. They concluded that there were no significant differences in the observed behavior at the all-red interval versus the non-all-red interval intersections.

CHAPTER 3 - STUDY METHODOLOGY

Introduction

The accident history at an intersection is a widely accepted measure of traffic safety [FHWA, 1982]. Although the all-red clearance interval's short term effect on accidents and accident rates has been documented in Chapter Two, no research has been published to conclude if those effects are sustained longer than one year after implementation. For this study, annual Indiana accident data were used to evaluate intersection accident rates from two years before to five years after implementation of the all-red clearance interval. Rates for four different accident types (left turn, rear end, right turn, and right angle) as well as for the total number of accidents were considered.

Accident data for the years 1981 to 1987 were obtained for two groups of twenty-five intersections. One group, designated as the treatment group, had received the all-red clearance interval between 1982 and 1985. The other group, designated as the comparison group, had not received the all-red interval. To be examined, treatment group intersections had to meet the eligibility requirements discussed in this chapter for the length of time before and after the all-red interval implementation. The comparison group intersections were matched with the treated group based on entering volume, angle of intersect, and approach speed limits. From traffic volume counts, the estimated exposure at each intersection was calculated. Several statistical methods were used to analyze the resulting accident rates. To assess the relationship between treated and comparison intersections, the Wilcoxon Signed Rank test was employed. The Student's t-test was used to compare accident rates at treated intersections before and after the introduction of the all-red interval. The Chi-square test also aided in the examination of the before and after data at treatment intersections. In addition, three all-red interval accident studies noted in the literature review were reproduced with treated intersection data to see if the conclusions would be the same.

Sample of Intersections

Ideally, a large number of intersections would be included in this study. However, the unsuitability of pre-1981 accident data and the availability of intersection volume counts from INDOT reduced the sample size of those sites "treated" with an all-red interval to twenty-five. An equivalent number of comparison intersections were also chosen. Table 1 lists the sample locations of the all-red interval treated group while Table 2 lists those of the comparison group. All of the locations selected were four-approach intersections with two-way traffic on each approach. To avoid potential confounding of factors, all four approaches of each intersection met in the same location; that is, the intersection was not offset. As shown in Tables 3 and 4, twenty-one of the pairs had approach angles of 90 degrees, while the remaining four pairs had angles ranging from 50 to 70 degrees.

This study did not control for all variables that may have affected

Table 1
Treatment Intersection Locations and Dates
of Signal and All-Red Interval Installation

Group Number	Intersection Location	City	Signal Installation	All-Red Implementation
101	SR 39/Lebanon Street @ Camp Street	Lebanon	xx/xx/67	xx/xx/85
102	US 421/Main Street @ Madison Street	Kirklin	xx/xx/80	xx/xx/85
103	US 40 @ SR 39	Belleville	xx/xx/7x	08/08/85
104	US 41/3rd Street @ Voorhees Street	Terre Haute	xx/xx/64	xx/xx/85
105	SR 9-109/Scatterfield Road @ SR 236/53rd Street	Anderson	xx/xx/5x	01/25/83
106	US 40/Washington Street @ High School Road	Indianapolis	xx/xx/5x	09/28/82
107	US 52/Brookville Road @ Post Road	Indianapolis	xx/xx/5x	02/03/83
108	US 31/Meridian Street @ 46th Street	Indianapolis	xx/xx/5x	05/20/82
109	US 31/Meridian Street @ 49th Street	Indianapolis	xx/xx/5x	05/20/82
110	US 40/Washington Street @ Arlington Street	Indianapolis	xx/xx/5x	06/08/82
111	US 31/Meridian Street @ 56th Street	Indianapolis	xx/xx/4x	10/04/82
112	US 31/Meridian Street @ 52nd Street	Indianapolis	xx/xx/5x	05/20/82
113	SR329/Burlington Avenue/ Third Street @ SR 435/Main Street	Logansport	02/21/51	08/02/83
114	US 231/Washington Street @ Van Rensselaer Street	Rensselaer	10/18/74	10/09/85
115	US 41/Calumet Avenue @ 141st Street	Hammond	11/15/51	04/25/83
116	SR 53/Broadway Avenue @ 73rd Avenue	Merrillville	06/02/50	04/20/83
117	US 41/Indianapolis Boulevard @ Martha Street	Highland	04/05/65	06/27/83
118	US 33/Michigan Street @ North Shore Drive	South Bend	11/01/51	03/29/85
119	US 33/Lincolnway East @ Ironwood Drive	South Bend/ Mishawaka	11/01/51	03/07/85
120	SR 331/Main Street @ Mishawaka Avenue	Mishawaka	01/01/39	07/16/85
121	SR 23/South Bend Avenue @ Ironwood Road	Mishawaka	12/29/55	09/13/83
122	US 33/Lincolnway Avenue @ SR 219/Ash Road	Osceola	11/13/62	12/13/85
123	SR 331/Union Street @ Dragoon Trail	Mishawaka	06/01/78	05/21/84
124	SR 57/4th Street @ US 50	Washington	03/07/63	05/11/84
125	SR 441/Willow Street @ 15th Street	Vincennes	06/10/66	02/24/83

Table 2
Comparison Intersection Locations

Group Number	Intersection Location	City
201	US 40/Washington Street @ Fleming Street	Indianapolis
202	US 40 @ SR 103/First Street	Lewisville
203	US 136/Washington Street @ Vine Street	Waynetown
204	SR 23/Eddy Street @ LaSalle Street	South Bend
205	SR 26/South Street @ Earl Avenue	Lafayette
206	SR 152/Indianapolis Boulevard @ Summer Street	Hammond
207	SR 331/Main Street @ Jefferson Street	Mishawaka
208	SR 53/Broadway Avenue @ 68th Place	Merrillville
209	SR 152/Indianapolis Boulevard @ 171st Street	Hammond
210	SR 37/38th Street @ Pennsylvania Avenue	Indianapolis
211	US 41/3rd Street @ Locust Street	Terre Haute
212	US40/Main Street @ 30th Street/Henley Road	Richmond
213	US 231/4th Street @ Romig Street	Lafayette
214	US231/Main Street @ SR 64/6th Street	Huntingburg
215	SR 55/Cleveland Avenue @ 45th Avenue	Merrillville
216	US 40/Washington Street @ Sherman Drive	Indianapolis
217	US 35/SR 39/Indiana Avenue @ SR 2-39/Lincolnway	LaPorte
218	SR 53/Broadway Avenue @ 45th Avenue	Gary
219	SR 32-38/Conner Street @ 10th Street	Noblesville
220	US 40/Washington Street @ Kitley Avenue	Indianapolis
221	US 36/SR 67/Pendleton Pike @ Post Road	Lawrence
222	US 136/Main Street @ SR 267/Green Street	Brownsburg
223	SR 61/6th Street @ Niblack Boulevard	Vincennes
224	US 40/Main Street @ Center Street	Plainfield
225	US 135/Crawfordsville Road @ Tansel Road	Clermont

Table 3
Treatment Intersection Data

Group Number	Approach Angle	Speed Limit (mph) N	S	E	W	1984 Entering Volume (Est.)
101	70	30	30	20	20	7,260,152
102	90	30	30	20	20	1,565,991
103	90	30	30	40	40	1,678,440
104	90	40	40	30	30	13,655,678
105	90	45	45	45	45	10,629,205
106	60	35	35	40	40	18,182,987
107	90	40	40	50	50	10,231,593
108	90	30	30	35	35	12,598,788
109	90	35	35	30	30	11,486,560
110	90	35	35	35	35	15,217,468
111	90	40	40	30	30	10,524,227
112	90	35	35	30	30	11,225,801
113	90	30	30	35	20	5,798,524
114	90	20	20	20	20	4,673,997
115	90	45	45	20	20	8,580,002
116	90	35	35	30	20	12,825,947
117	90	35	35	20	20	12,868,908
118	90	35	35	30	30	10,661,649
119	90	30	30	35	35	11,861,383
120	90	35	35	20	20	11,768,719
121	55	30	30	25	25	13,950,824
122	90	55	20	45	45	9,436,645
123	90	35	35	40	30	7,318,425
124	90	30	30	30	30	8,652,854
125	50	35	35	30	30	5,569,230

Table 4
Comparison Intersection Data

Group Number	Approach Angle	Speed Limit (mph) N	S	E	W	1984 Entering Volume (Est.)
201	60	20	20	40	40	8,819,286
202	90	30	30	30	30	1,376,859
203	90	20	20	30	30	1,440,669
204	90	35	35	30	30	13,491,018
205	90	35	35	35	35	10,607,551
206	50	35	35	30	30	18,600,675
207	90	35	35	30	30	10,307,922
208	90	35	35	20	20	12,450,007
209	90	35	35	20	20	11,456,126
210	90	30	30	35	35	15,950,209
211	90	40	40	30	30	10,515,742
212	90	20	30	30	30	11,175,590
213	90	25	25	20	20	5,783,390
214	90	25	25	25	25	5,586,285
215	90	35	35	30	30	8,412,961
216	90	35	35	35	35	12,635,512
217	90	25	25	25	25	12,262,258
218	90	30	30	20	20	10,696,067
219	90	20	20	20	20	11,951,289
220	90	30	30	35	35	11,443,540
221	60	35	40	40	40	13,817,288
222	90	30	30	30	30	9,626,960
223	90	30	30	35	35	7,319,437
224	90	30	30	30	30	8,799,981
225	60	25	25	30	30	5,744,905

accident rates at these intersections. Some of the variables that were not examined include:

-length and adequacy of the all-red clearance interval

-warrant for installing the all-red interval

-existence/location of detectors

-type of signal (fixed time, semi- or fully-actuated)

-changes in phasing and length of signal cycle

-number of lanes on approach, including left turn lanes

-additional developments/driveway cuts

-travel speeds different from posted speed limits

-changes in traffic mix over the study period

-levels of service throughout the study period

To study the effect of each of these factors, a data base much larger than the one assembled for this project would be required. Since most of the historical data listed above was not gathered over time, the conduct of such an all-encompassing study for this project is impossible.

Data Collection

To obtain much of the necessary intersection data, written and telephone requests were made to four of INDOT's six district traffic engineers. Changes in the data set, such as incomplete accident data or unsuitable geometries, necessitated several iterations of these requests to obtain satisfactory information. Ultimately, visits to the INDOT traffic engineers' offices proved to be the quickest method of obtaining satisfactory information. This phase of the study lasted twenty months.

There were large populations of both treated and untreated intersections from which the two sample groups were drawn. Due to the limitations imposed by traffic signal data requirements and by turning movement count availability (see sections below), the maximum sample size that could be employed within a reasonable period of time was twenty-five.

Traffic Signal Data

The dates of traffic signal installation and all-red interval implementation defined the eligibility of intersections for this study. With pre-1981 accident data unavailable and post-1985 all-red interval implementations too recent to allow an after period of adequate length, only sites with the all-red interval installed during the years 1982 through 1985 were considered. In addition, the installation date of the signal must have preceded the all-red interval implementation by a minimum of two years. This allowed the accident data to be analyzed for long-term (3-5 years) effects.

The four INDOT district traffic offices searched their signal files to provide the traffic signal installation and all-red interval implementation dates. In many instances, the all-red interval dates were specified to the day. Most signal installations, however, could only be dated by decade. Table 1 lists both sets of dates (MM/DD/YY) for the treated group. Unknown listings are denoted in the tables by XX. Although more accuracy was desired, this lack of information did not impair the progress of the study.

Traffic Volume Data

Traffic volume counts for computing accident exposure were obtained from the INDOT district traffic offices. Although most of the counts were taken over twelve-hour periods, some were based on as little as four hours. All of the counts were performed by INDOT personnel within the last ten years. Since INDOT did not perform traffic counts at all signalized locations, obtaining enough counts for acceptable locations required several rounds of requests. Each volume count was expanded from several hours to an annual figure using the appropriate INDOT-developed temporal and seasonal adjustment factors, which were based on the month and year of the actual count. To account for yearly traffic growth, the INDOT-adopted factor of 187.5 percent increase over 19 years was used. Equivalently, INDOT assumed traffic grows at approximately 3 percent per year. For ease in later calculations, the annual volumes were converted to year 1984 entering volumes. The year 1984 was chosen arbitrarily because it was the middle year of the period analyzed. Table 3 lists annual volumes of the treated group of intersections, while Table 4 lists those of the comparison group.

Geometric and Speed Limit Data

Geometric and speed limit data were initially obtained from the INDOT district traffic offices and from subsequent visits to the intersection locations. The approximate angle of the intersection and the speed limits on each approach were recorded. A few of the residential areas with posted speed limit signs limited travel to 20 miles per hour. Since most residential areas did not post speed limit signs for speeds under 25 miles per hour, all unsigned residential areas were assumed to be limited to 20 miles per hour. Table 3 lists approach angle and speed limits for the treated group while Table 4 denotes those of the comparison group. In addition, a telephone survey of INDOT district traffic engineers ascertained that no significant geometric changes occurred at the study sites during the 1980s. At this point, each treated intersection was paired as closely as possible with a comparison group intersection, as described in the next section.

Comparison Group

A comparison group of intersections was selected to provide a basis for comparing the treated intersections with those that had not received the all-red interval. The problems associated with obtaining volume counts greatly hampered the task of finding the best possible matches for the treatment group. In addition, many locations that had not received an all-red interval were signalized after 1980. Since the signal needed to be in place throughout the entire study period from 1981 to 1987, these sites were disqualified from the comparison group.

To match the comparison group as closely as possible, a combination of entering traffic volumes, approach speed limits, and angles of intersect were used. Of the three, the intersection angle proved to be the easiest match and speed limit the most difficult. Although each comparison intersection does not exactly match its counterpart's characteristics, the pairing was close enough to provide a valid basis for examining the relationship between their accident rates. A listing of the comparison group intersections is shown in Table 2.

Accident Data

Accident tapes containing coded information for all reported accidents in the State of Indiana were obtained from the State Police. Only data coded from 1981 on could be utilized for this study; the data format used prior to 1981 did not list a cross street for the accident location. This made it impossible to assign an accident to a particular intersection.

Initially, INDOT provided a hard-copy listing of accidents that occurred near intersections of interest for the years 1985-1987. Subsequent changes in the sample, due to the unsuitability of pre-1981 accident data, rendered the hard-copy information obsolete. The changing sample, coupled with INDOT's limited accident program, required the creation of a set of programs to extract accident data from Indiana State Police data tapes. This task was undertaken on the mainframe computer system of the School of Civil Engineering at Purdue University.

The development of the programs to read post-1980 data tapes started with the formulation of an input file. All previously collected data (location, traffic signal dates, 1984 traffic volume, intersection angle, speed limits) were included and reproduced in the output for easy reference. Additionally, each location was described by one or more pairs of pseudo-road number codes. Each six-digit number corresponds to a particular roadway name. For roads with more than one name, such as US 31/Meridian Street in Indianapolis, each name's pseudo-road number must be listed separately. Tables 1 and 2 indicate the names assigned to each location.

Since the annual number of accidents recorded statewide nearly filled one magnetic tape, data were extracted one year at a time. The programs searched for accident locations that matched the previously mentioned pairs of pseudo-road numbers. To account for post-impact vehicle motion, accidents within 200 feet of the intersection were included. Each year's data required approximately two hours (real time) to extract from the data tape by computer.

After the data for each year were extracted, a hard-copy summary of these accidents was examined. The date, time, collision diagram, vehicles involved, and other aspects of each accident were listed. Errors, such as an improper city listing, could occur due to having the same street name in two different towns. The most prevalent of these errors occurred with Huntingburg and Jasper. Both cities had an intersection of US 231 with SR 64. After deleting such erroneous listings from the results, the data summaries were ready for the statistical tests.

Statistical Tests

To interpret the accident data that had been gathered, several statistical tests were utilized. The Wilcoxon Signed Rank test, the Student's t-test, and the Chi-square test provided the framework for assessing the safety effects of the all-red interval in both the short term and the long term. Also, the statistical comparisons used in three of the prior all-red interval studies were recalculated with Indiana data. The results of these tests and a discussion of their meaning can be found in the next chapter.

Wilcoxon Signed Rank Test

The Wilcoxon Signed Rank test was selected for statistical comparison between the paired treatment and comparison intersection accident rates. This non-parametric test is based on the signed rank of the accident rate differences for these twenty-five intersection pairs. Because a normal distribution of accident rate differences is not assumed, the test can be used to compare two probability distributions (such as treated and comparison intersections) within a matched pair design [Scheaffer and McClave, 1986].

The test asserts that, if there is no significant difference between two sets of paired measurements, an equal number of plus and minus differences should exist [Langley, 1964]. Since this test takes into account the sign and the magnitude of these differences, the sensitivity of the test reaches a point where it compares favorably with the more complicated t-test.

With minimal assumptions about the population, this test was simple to implement. First, the absolute values of each of the differences between paired observations were ranked from smallest to largest, with differences equal to zero discarded and with the ranks of equal differences averaged. For example, if a treatment intersection accident rate minus its matched comparison intersection accident rate equaled zero, the pair was dropped from consideration for that particular test. If two or more pairs of those intersections had equal differences (such as 2.875), the ranks they held (say 3rd and 4th) were averaged and assigned to each. Then, the sign of the difference was affixed to each rank. Finally, the positive and negative ranks were summed separately. For the two-tailed test, the smaller absolute value of the two summed ranks was used as the test sum to compare against the critical sum.

If the null hypothesis that the treatment and comparison populations were identical was true, it would be expected that the positive and negative sums would be similar. This is because the number of larger ranks with positive signs would be approximately equal to the number of larger ranks with negative signs [Chao, 1984]. If the test sum is greater than the critical sum, based on sample size and a two-tailed test at the five percent significance level, the accident rates between the treated and comparison intersections can be said to be significantly different. In other words, the distribution of signs must be sufficiently lopsided to indicate a difference in accident rates.

To seek out different factors of interest, one hundred seventy-five different comparisons between treated and comparison intersection accident rates were attempted. Rates for four different accident types (left turn, rear end, right turn, and right turn angle) and for the total number of accidents, spanning seven calendar years, were examined for the four treatment year groupings, as well as a combined grouping. By comparing the treatment group to the comparison group with a two-tailed test, a determination can be made about the short- and long-term accident rate reduction ability of the all-red interval.

Student's t-test

The Student's t-test was selected for a statistical comparison of intersection accident rates one and two years before and after the addition of the all-red interval. Comparison intersections' accident rates were compared for the same before and after time frames as their corresponding treatment intersections. In addition, the accident rates at the treatment intersections during the treatment year were compared separately to one year before and one year after the all-red interval. The Student's t-test is based on the differences between mean accident rate in the before and after periods. A two-tailed test was performed at the five percent significance level. Although a symmetric t distribution of accident rate differences must be assumed, the test can be used for making inferences about differences between two population means within a matched pair design [Neter et al., 1988].

For the two-tailed test, the null hypothesis for the difference in population means between the before and after periods asserts that the before period's and the after period's mean accident rates are equal. Comparison with the critical value (which is based on the data and the sample size) determined if the mean accident rates for the before and after periods differed significantly. The null hypothesis was true if the absolute value of the test statistic was less than or equal to the critical value. In other words, the difference in accident rates must be outside a certain range to be considered significant.

In an attempt to isolate different factors of interest, twenty different comparisons between before and after intersection accident rates were made. Rates for four different accident types (left turn, rear end, right turn, and right turn angle) and for the total number of accidents were examined for both treatment and comparison intersections. The comparisons looked at one and two years before the introduction of the all-red interval versus one and two years after. In addition, two separate comparisons were made of total accident rates in the treatment year versus one year before and one year after. From these comparisons, a determination can be made about the short-term and medium-term accident rate reduction ability of the all-red interval.

Chi-Square test

The Chi-square test was selected for the statistical comparison of accident rates at each treated intersection. The data for one year before and one to three years after the addition of the all-red interval were used because the years prior and subsequent to those years excluded portions of the treatment group. This test is based on the differences between the observed and expected accident rates at the intersections during those years. The expected value is calculated by determining the average accident rate for each intersection over the four years (total accidents divided by total volume) and multiplying that value by the volume of a given year.

In an attempt to isolate different factors of interest, accident rates at each intersection were compared against the expected value. Rates at each intersection for four different accident types (left turn, rear end, right turn, and right turn angle) and for the total number of accidents were tested for treatment intersections. From this test a determination can be made about the criteria used to describe the treatment year.

Tests in the Literature

As noted in the previous chapter, the conclusions of several of the early all-red interval studies were based on changes in the total number of accidents. By not considering accidents per million entering vehicles as another indicator of relative safety, their results may have been biased. With this in mind, three of these early studies have been adapted with as few changes as possible using Indiana data. From the results, some comments can be made concerning each study.

Newby [1961] compared injury accidents at twelve sites for two years before and after the addition of the all-red interval. These periods immediately preceded and followed all-red interval installation. The total number of injury accidents in the after period were significantly reduced, due mostly to the decrease in two-vehicle injury accidents. For the Indiana study, the two year before and after periods are separated by a single "treatment year." Aside from this change, injury accident data from these periods were compared. The results can be found in the next chapter.

Wilson [1965] compared total accidents at eighteen sites for one year before and after the removal of the all-red interval. Total accidents after the removal increased 5.2 percent over the before period total. For the Indiana study, the total number of accidents for a one-year before and after period were compared. Since an all-red interval has been added rather than removed, it would be expected that the number of accidents would be reduced in the after period. The results can be found in the next chapter.

Conradson and Bunker [1972] compared total accidents at seventeen sites for one-year before and one-year after the addition of the all-red interval. Overall, total accidents after the addition of the all-red interval decreased significantly. This significance was determined by conducting a before and after period comparison of the total accident rate for the seventeen sites (sum of the site volumes divided by the sum of the site accidents). For the Indiana study, the two year before and after periods are separated by a single "treatment year." Aside from this change, injury accident data from these periods were compared. The results can be found in the next chapter.

CHAPTER 4 - RESULTS AND DISCUSSION

Introduction

The all-red clearance interval has been praised for thirty years for its ability to reduce accidents, albeit in the short term. To determine whether these claims hold up to thorough statistical testing, the Indiana data were subjected to several different analyses. In addition to the six different statistical and literature-based tests described in the previous chapter, graphs of each accident rate type were plotted to assess general trends. The results of these examinations and a discussion of their meaning are included in this chapter.

Graphical Analysis

Five graphs relating average accident rates (per million entering vehicles) of the treated sample to the years before and after treatment were studied. For each graph, the average accident rates for three treatment years (1982, 1983, 1985) and of a combined total were plotted from two years before to four years after the all-red interval was implemented. Since only two intersections were in the treatment group for the year 1984, a plot for that year was not produced. In addition, one segment of the graph is missing for the treatment years 1982 and 1985. This is because accident data were limited to the years 1981-1988.

Total Accident Rates

By examining Figure 1, it can be determined that the total accident rates decreased in the calendar year the all-red interval was added (year 0). This decline reversed itself over the following four years, with total accident rates for the total sample returning to the levels that existed before the all-red intervals were installed. Several interpretations of this graph are possible. It can be interpreted as evidence of the all-red clearance interval's short-term ability to reduce accident rates and perhaps the rate of increase from its previous trend. On the other hand, it can be interpreted as evidence of the all-red interval's inability to keep accident rates down over time. Consequently, no clear cut conclusion can be made from this graph alone.

Left Turn Accident Rates

By examining Figure 2, it can be determined that the total left turn accident rates leveled off in the calendar year the all-red interval was added (year 0). Over the following four years, left turn accident rates for the total sample remained relatively constant. This graph could be interpreted as evidence of the all-red clearance interval's short-term ability to convert rising accident rates into a stable rate. On the other hand, the plots from the three individual treatment years are so variable that no clear cut conclusion can be made from these plots in Figure 2 alone.

Rear End Accident Rates

By examining Figure 3, it can be determined that the total rear end

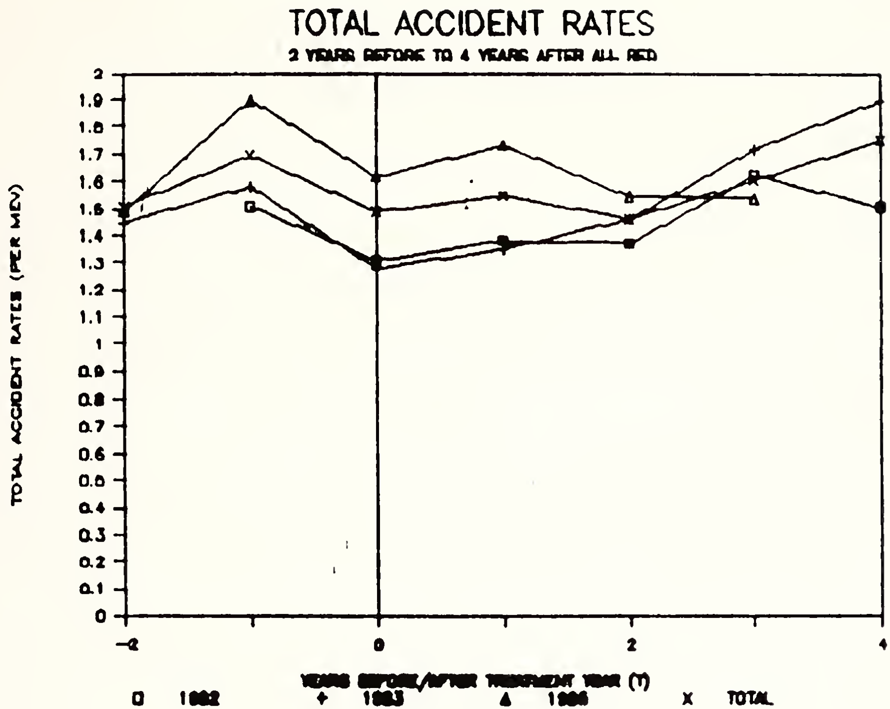

Figure 1
Total Accident Rates

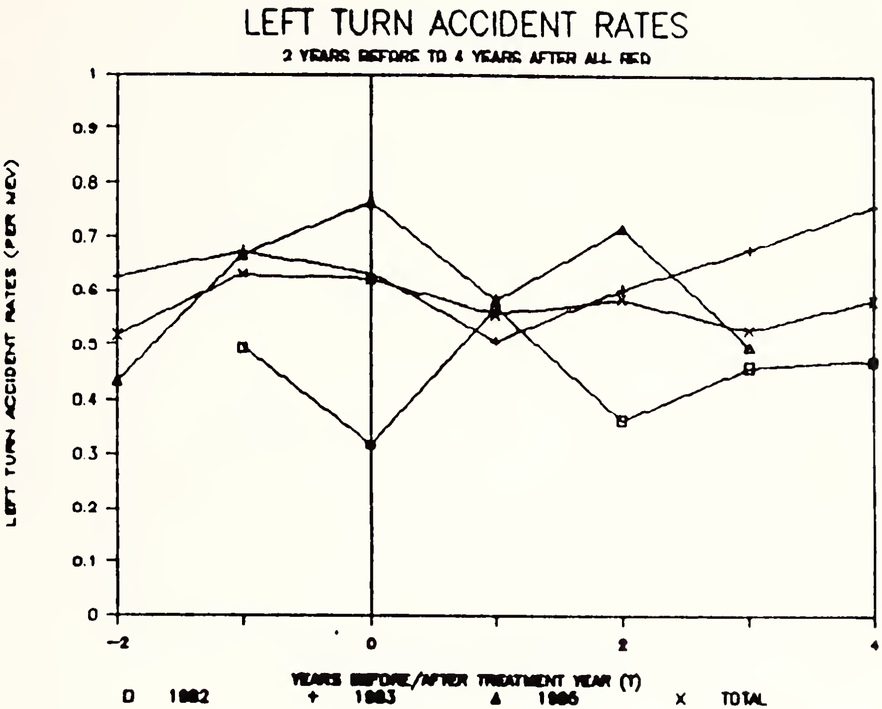

Figure 2
Left Turn Accident Rates

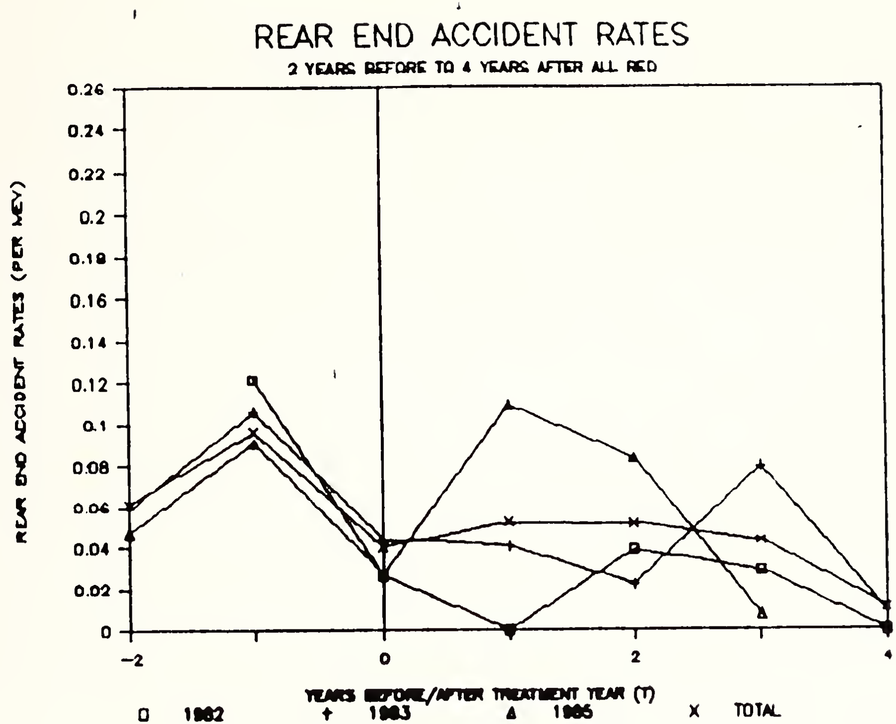

Figure 3
Rear End Accident Rates

accident rates decreased markedly in the calendar year the all-red interval was added (year 0). A more modest decline for the total sample continued over the following four years. This can be interpreted as evidence of the all-red clearance interval's ability to reduce accident rates in the short term to prevent a return to the rate of increase shown before the treatment year. This is somewhat unexpected, in light of the literature. On the other hand, the year-to-year volatility in rates for the three separate treatment years casts doubts on the all-red interval's ability to keep accident rates down over time. Consequently, no clear cut conclusion can be made from this graph alone.

Right Turn Accident Rates

By examining Figure 4, it can be determined that the total right turn accident rates decreased in the calendar year the all-red interval was added (year 0). This decline reversed itself over the following four years, with right turn accident rates for the total sample returning to the levels that existed before the all-red intervals were installed. Several interpretations of this graph are possible. It can be interpreted as evidence of the all-red clearance interval's short-term ability to reduce accident rates and perhaps the rate of increase from its previous trend. On the other hand, it can be interpreted as evidence of the all-red interval's inability to keep accident rates down over time. Consequently, no clear cut conclusion can be made from this graph alone.

Right Angle Accident Rates

By examining Figure 5, it can be determined that the total right

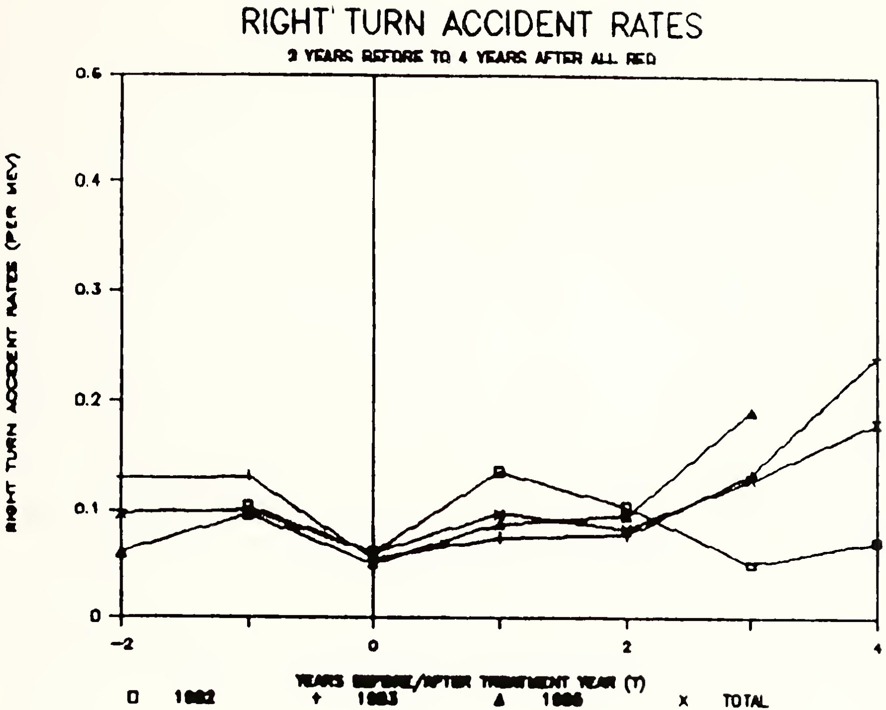

Figure 4
Right Turn Accident Rates

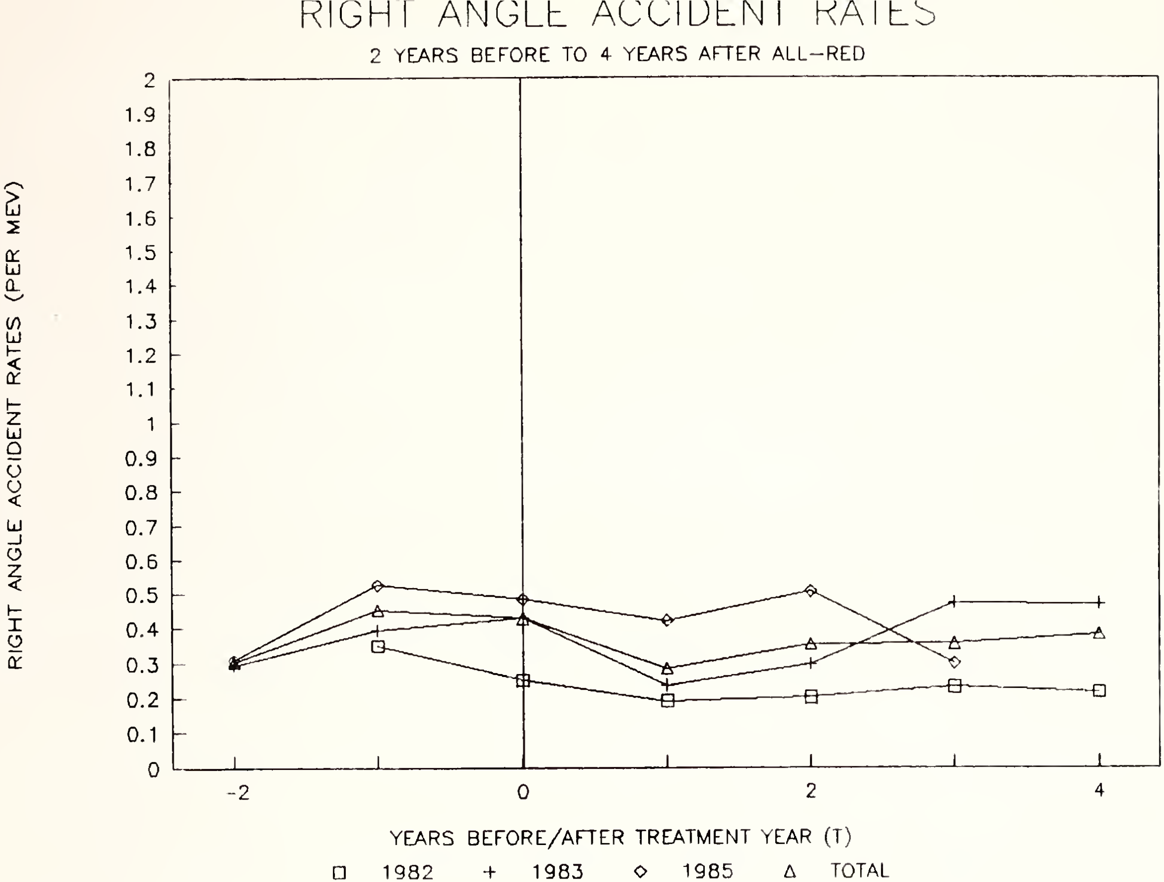

Figure 5. Right Angle Accident Rates

angle accident rates declined slightly in the calendar year and all-red interval was added (year 0). After a steeper decline in year 1, the rates for the total sample remained nearly constant. This graph could be interpreted as evidence of the all-red clearance interval's short-term ability to reduce accident rates. On the other hand, the plots from the three individual treatment years are so variable that no clear cut conclusion can be made from these plots alone.

Wilcoxon Signed Rank Test

Five sets of comparisons between yearly accident rates (per million entering vehicles) of the treated group and those of the comparison group were conducted. Rates for four different accident types (left turn, rear end, right turn, and right turn angle) and for the total number of accidents, spanning seven calendar years, were examined for the four treatment year groupings as well as a combined grouping. The two-tailed test required a minimum group size of six [Scheaffer and McClave, 1986]. Because the group size of the treatment year 1984 consisted of only two intersections--fewer than the six necessary [Scheaffer, 1986]--the test was not performed for that year's data.

Total Accident Rates

The results of the two-tailed test, which are found in Table 5, indicate that no difference exists between the total accident rates of the two groups over time. For none of the twenty-eight comparisons was the test sum less than the critical sum. These results can be interpreted as evidence of the all-red clearance interval's inability to reduce either

Table 5
Two-tailed Wilcoxon Signed Rank Test Results
(Total and Left Turn Accident Rates)

CALENDAR YEAR	TREATMENT YEAR	TOTAL ACCIDENT RATES					LEFT TURN ACCIDENT RATES				
		n	Test Sum		Critical Sum	RESULT	n	Test Sum		Critical Sum	RESULT
1981	1982	6	9	>	1	H_0	6	8	>	1	H_0
	1983	8	7	>	4	H_0	8	11	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	8	17	>	4	H_0	8	17	>	4	H_0
	1982-85	24	141	>	81	H_0	24	143	>	81	H_0
1982	1982	6	8	>	1	H_0	6	8	>	1	H_0
	1983	8	4	=	4	H_0	8	11	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	9	22	>	6	H_0	9	21	>	6	H_0
	1982-85	25	143	>	90	H_0	25	155	>	90	H_0
1983	1982	6	7	>	1	H_0	6	3	>	1	H_0
	1983	8	8	>	4	H_0	8	9	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	9	16	>	6	H_0	9	19	>	6	H_0
	1982-85	25	160	>	90	H_0	25	83	<	90	H_1
1984	1982	6	10	>	1	H_0	6	10	>	1	H_0
	1983	8	6	>	4	H_0	8	12	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	9	15	>	6	H_0	8	7	>	4	H_0
	1982-85	25	146	>	90	H_0	24	114	>	81	H_0
1985	1982	6	10	>	1	H_0	6	4	>	1	H_0
	1983	8	7	>	4	H_0	8	15	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	9	21	>	6	H_0	9	16	>	6	H_0
	1982-85	25	151	>	90	H_0	25	144	>	90	H_0
1986	1982	6	10	>	1	H_0	6	9	>	1	H_0
	1983	8	9	>	4	H_0	8	16	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	9	21	>	6	H_0	8	11	>	4	H_0
	1982-85	25	147	>	90	H_0	24	124	>	81	H_0
1987	1982	6	10	>	1	H_0	6	10	>	1	H_0
	1983	8	9	>	4	H_0	8	15	>	4	H_0
	1984	2	-		-	-	2	-		-	-
	1985	8	11	>	4	H_0	8	16	>	4	H_0
	1982-85	24	147	>	81	H_0	24	142	>	81	H_0

H_0: Therefore, no statistically significant difference in accident rates between the treatment group and the comparison group.
H_1: Therefore, there is a statistically significant difference in accident rates between the treatment group and the comparison group.

(a) the total accident rates over time or (b) the rate of increase from its previous level.

Left Turn Accident Rates

The results of the two-tailed test, which are found in Table 5, indicate that no difference exists between the left turn accident rates of the two groups over time. In only one of the twenty-eight comparisons was the test sum less than the critical sum. This result implies that the one intersection that showed a difference with the two-tailed test had higher accident rates at the treatment intersections than at the comparison intersections. This can be interpreted as evidence of the all-red clearance interval's inability to reduce either the left turn accident rates or the rate of increase from its previous level.

Rear End Accident Rates

The results of the two-tailed test, which are found in Table 6, indicate that no difference exists between the accident rates of the two groups over time. For none of the thirteen comparisons was the test sum less than the critical sum. This can be interpreted as evidence of the all-red clearance interval's inability to reduce either the total accident rates or the rate of increase from its previous level. Since thirteen of the twenty-eight comparisons were not performed due to lack of rear end accidents at both intersections, however, these results are not as conclusive as the other comparisons.

Table 6
Two-tailed Wilcoxon Signed Rank Test Results
(Rear End and Right Turn Accident Rates)

CALENDAR YEAR	TREATMENT YEAR	REAR END ACCIDENT RATES					RIGHT TURN ACCIDENT RATES				
		n	Test Sum		Critical Sum	RESULT	n	Test Sum		Critical Sum	RESULT
1981	1982	5	-		-	-	6	6	>	1	H_0
	1983	6	6	>	1	H_0	8	13	>	4	H_0
	1984	1	-		-	-	1	-		-	-
	1985	5	-		-	-	6	9	>	1	H_0
	1982-85	17	75	>	35	H_0	21	96	>	59	H_0
1982	1982	2	-		-	-	6	6	>	1	H_0
	1983	6	11	>	1	H_0	8	10	>	4	H_0
	1984	2	-		-	-	1	-		-	-
	1985	3	-		-	-	6	7	>	1	H_0
	1982-85	13	40	>	17	H_0	21	95	>	59	H_0
1983	1982	3	-		-	-	6	4	>	1	H_0
	1983	7	7	>	2	H_0	7	10	>	2	H_0
	1984	0	-		-	-	0	-		-	-
	1985	4	-		-	-	6	7	>	1	H_0
	1982-85	14	32	>	21	H_0	19	89	<	46	H_0
1984	1982	4	-		-	-	5	-		-	-
	1983	6	5	>	1	H_0	6	8	>	1	H_0
	1984	2	-		-	-	1	-		-	-
	1985	3	-		-	-	6	10	>	1	H_0
	1982-85	15	59	>	25	H_0	18	81	>	40	H_0
1985	1982	4	-		-	-	5	-		-	-
	1983	3	-		-	-	6	5	>	1	H_0
	1984	0	-		-	-	2	-		-	-
	1985	4	-		-	-	5	-		-	-
	1982-85	11	38	>	11	H_0	18	44	>	40	H_0
1986	1982	1	-		-	-	6	7	>	1	H_0
	1983	6	8	>	1	H_0	8	18	>	4	H_0
	1984	1	-		-	-	1	-		-	-
	1985	6	6	>	1	H_0	7	12	>	2	H_0
	1982-85	14	34	>	14	H_0	22	103	>	66	H_0
1987	1982	4	-		-	-	6	7	>	1	H_0
	1983	3	-		-	-	8	17	>	4	H_0
	1984	2	-		-	-	1	-		-	-
	1985	3	-		-	-	5	-		-	-
	1982-85	12	34	>	14	H_0	20	91	>	52	H_0

H_0: Therefore, no statistically significant difference in accident rates between the treatment group and the comparison group.
H_1: Therefore, there is a statistically significant difference in accident rates between the treatment group and the comparison group.

Right Turn Accident Rates

The results of the two-tailed test, which are found in Table 6, indicate that no difference exists between the right turn accident rates of the two groups over time. For none of the twenty eight comparisons was the test sum less than the critical sum. This can be interpreted as evidence of the all-red clearance interval's inability to reduce either the right turn accident rates or the rate of increase from its previous level.

Right Angle Accident Rates

The results of the two-tailed test, which are found in Table 7, indicate that no difference exists between the right angle accident rates of the two groups over time. For none of the twenty-seven comparisons was the test sum less than the critical sum. This can be interpreted as evidence of the all-red clearance interval's inability to reduce either the right angle accident rates or the rate of increase from its previous level.

Student's t-Test

Five types of annual accident rates (per million entering vehicles) for the treated group and the comparison group were examined independently with two-tailed tests. To accomplish before-and-after comparisons, the average accident rates for the treated group for one-and two-year periods preceding the implementation of the all-red interval were compared against average accident rates during the same length of time following the all-red interval. The same comparisons were performed for the comparison

Table 7
Two-tailed Wilcoxon Signed Rank Test Results
(Right Angle Accident Rates)

CALENDAR YEAR	TREATMENT YEAR	RIGHT ANGLE ACCIDENT RATES				
		n	Test Sum		Critical Sum	RESULT
1981	1982	6	8	>	1	H_0
	1983	8	5	>	4	H_0
	1984	2	-		-	-
	1985	8	17	>	4	H_0
	1982-85	24	117	>	81	H_0
1982	1982	6	10	>	1	H_0
	1983	8	11	>	4	H_0
	1984	2	-		-	-
	1985	9	17	>	6	H_0
	1982-85	25	137	>	90	H_0
1983	1982	6	9	>	1	H_0
	1983	8	11	>	4	H_0
	1984	2	-		-	-
	1985	8	13	>	4	H_0
	1982-85	24	104	>	81	H_0
1984	1982	6	9	>	1	H_0
	1983	8	5	>	4	H_0
	1984	2	-		-	-
	1985	9	14	>	6	H_0
	1982-85	25	159	>	90	H_0
1985	1982	6	9	>	1	H_0
	1983	8	6	>	4	H_0
	1984	2	-		-	-
	1985	9	21	>	6	H_0
	1982-85	25	147	>	90	H_0
1986	1982	5	-		-	-
	1983	8	13	>	4	H_0
	1984	2	-		-	-
	1985	9	15	>	6	H_0
	1982-85	24	108	>	81	H_0
1987	1982	6	6	>	1	H_0
	1983	8	9	>	4	H_0
	1984	2	-		-	-
	1985	8	10	>	4	H_0
	1982-85	24	139	>	81	H_0

H_0: Therefore, no statistically significant difference in accident rates between the treatment group and the comparison group.
H_1: Therefore, there is a statistically significant difference in accident rates between the treatment group and the comparison group.

group, with the treatment year linked to each intersection's matched twin in the treatment group. In addition, the accident rates of the treatment intersections during the treatment year were compared separately to one year before and one year after the all-red interval. Table 8 summarizes the change in accident rates by accident type, for several different time periods:

- Treatment (all-red installation) year T vs. year T-1 and year T+1
- One year before and after, i.e., T-1 vs. T+1
- Two years before and after, i.e., (T-2) + (T-1) vs. (T+1) + (T+2)

The "mean change" units are accidents per million entering vehicles (MEV). Because this value has little intuitive meaning (except for its sign), the "percent change" is also given in Table 8.

A two-tailed student's t-test was carried out to test for a change in accident rate in either direction--decrease or increase. The test statistics calculated from the data have been converted into P values. If a P value is lower than a prescribed value of α (usually 0.05), the data support the conclusion that the accident rate has changed. If $P<\alpha$ in Table 8 and the mean change is negative, a reduction in accident rates can be concluded. A positive mean change indicates an increase in accident rate. In the discussion below, α = 0.05 was used, but a value as high as α=0.25 could have been used without changing the conclusions of the statistical analysis. Values of α greater than 0.10 are rare in this kind of analysis, so the results for our data set are not ambiguous.

Table 8
Change in Accident Rates; Student's t-Test Results

TREATMENT YEAR COMPARISON						
	Year (T-1) vs. Year (T)			Year (T) vs. Year (T+1)		
	Mean Change	Percent Change	P-value (see note)	Mean Change	Percent Change	P-value (see note)
Total Accident Rate	-0.203	-12.0	0.055	+0.057	+3.8	0.73
ONE YEAR BEFORE AND AFTER						
	TREATMENT GROUP			COMPARISON GROUP		
	Mean Change	Percent Change	P-value (see note)	Mean Change	Percent Change	P-value (see note)
Total Accident Rate	-0.146	-8.6	0.54	-0.054	-3.5	0.57
Left Turn Accident Rate	-0.631	-11.6	0.38	+0.045	+10.1	0.51
Right Turn Accident Rate	+0.007	+7.8	>0.90	-0.107	-52.1	0.006
Rear End Accident Rate	-0.044	-45.0	0.25	+0.020	+44.9	0.36
Right Angle Accident Rate	-0.153	-33.9	<0.001	-0.018	-5.1	0.72
TWO YEARS BEFORE AND AFTER						
	TREATMENT GROUP			COMPARISON GROUP		
	Mean Change	Percent Change	P-value (see note)	Mean Change	Percent Change	P-value (see note)
Total Accident Rate	-0.088	-5.4	0.38	-0.071	-4.2	0.51
Left Turn Accident Rate	+0.009	+1.5	0.91	+0.052	+10.7	0.50
Right Turn Accident Rate	-0.017	-17.8	0.51	-0.088	-45.0	0.02
Rear End Accident Rate	-0.013	-16.9	0.62	-0.009	-20.9	0.57
Right Angle Accident Rate	-0.024	-6.2	0.57	+0.028	+7.8	0.56

Note: If $|P| > \propto$, where $\propto$ is some specified level of significance (usually 0.05), the data do not indicate a significant change in accident rates. If $|P| < \propto$ and the mean change is negative, the data indicate a significant reduction in the accident rate.

Total Accident Rates

The results of the two-tailed test, which are found in Table 8, indicate that no difference exists between the total accident rates one or two years before and after the installation year of the all-red interval for either the treatment or the comparison group. This can be interpreted as further evidence of the all-red clearance interval's inability to reduce either the total accident rates over time or the rate of increase from its previous level.

Left Turn Accident Rates

The results of the two-tailed test, which are found in Table 8, indicate that no difference exists between the left turn accident rates one and two years before and after the all-red interval for either group. This can be interpreted as further evidence of the all-red clearance interval's inability to reduce either the left turn accident rates over time or the rate of increase from its previous level.

Rear End Accident Rates

The results of the two-tailed test, which are found in Table 8, indicate that no difference exists between the rear end accident rates one and two years before and after the all-red interval for either group. This can be interpreted as further evidence of the all-red clearance interval's inability to reduce either the rear end accident rates over time or the rate of increase from its previous level.

Right Turn Accident Rates

The results of the two-tailed test, which are found in Table 8, indicate that no difference exists between the right turn accident rates one and two years before and after the all-red interval for the treated group. This can be interpreted as further evidence of the all-red clearance interval's inability to reduce either the right turn accident rates over time or the rate of increase from its previous level. More unexpectedly, the accident rates of the comparison group were reduced in both after periods. This magnifies the extent to which the all-red interval did not perform in its ascribed manner.

Right Angle Accident Rates

The results of the two-tailed test, which are found in Table 8, indicate that a difference exists between the right angle accident rates one year before and after the all-red interval for the treated group. The difference did not extend to the two years before and after comparison. This finding can be interpreted as evidence of the all-red clearance interval's short-term, but not long-term, ability to reduce right angle accident rates. No difference exists between the comparison group accident rates for either time-dependent comparison.

Total Accident Rates - One Year Before and One Year After the Year of Treatment

The results of these two-tailed tests, which are found in Table 8, indicate that no difference exists between treatment year total accident rates and both one year before and one year after for the treatment year. This finding can be interpreted as evidence of the all-red clearance interval's inability to reduce total accident rates.

Chi Square Test

Five types of annual accident rates (per million entering vehicles) for the treated group were examined. To compare the differences in accident rates, the accident figures for the year before the all-red interval as well as the first three years after were used. From these comparisons, a determination can be made about the appropriateness of the criteria used to describe the treatment year.

Total Accident Rates

The results of this test, which can be found in Table 9, indicate that only two of the twenty-five intersections had total accident rates that differed over the four years of interest. This indicates that the total accident rate did not change appreciably over those four years. Consequently, it appears that the all-red clearance interval did little, if anything, to reduce total accident rates.

Left Turn Accident Rates

The results of this test, which can be found in Table 9, indicate that only two of the twenty-five intersections had left turn accident rates that differed over the four years of interest. This indicates that the left turn accident rate did not change appreciably over those four years. Consequently, it appears that the all-red clearance interval did little to reduce left turn accident rates.

Table 9
Chi-Square Test Results

INTERSECTION NUMBER	TREATMENT YEAR	TOTAL ACCIDENT RATES		LEFT TURN ACCIDENT RATES		REAR END ACCIDENT RATES		RIGHT TURN ACCIDENT RATES		RIGHT ANGLE ACCIDENT RATES	
		TEST STATISTIC	RESULT	TEST STATISTIC	RESULT	TEST STATISTIC	RESULT	TEST STATISTIC	RESULT	TEST STATISTIC	RESULT
1	1985	4.8317	H_0	3.3142	H_0	1.9723	H_0			4.2209	H_0
2	1985	7.0478	H_1	3.0380	H_0	2.1761	H_0	2.7795	H_0	2.1761	H_0
3	1985	1.8746	H_0	5.0955	H_0	2.9066	H_0	2.7795	H_0	2.7955	H_0
4	1985	13.8117	H_1	3.1910	H_0	1.9087	H_0	12.4072	H_1	1.4312	H_0
5	1983	5.2332	H_0	3.4216	H_0	5.7892	H_0	1.7656	H_0	4.0586	H_0
6	1982	2.4286	H_0	5.2605	H_0	14.5523	H_1	1.6549	H_0	2.4236	H_0
7	1983	0.8933	H_0	1.4611	H_0	2.0469	H_0			1.9678	H_0
8	1982	4.5013	H_0	2.3322	H_0	3.3142	H_0	2.0469	H_0	2.5962	H_0
9	1982	0.1157	H_0	1.6427	H_0	3.3142	H_0	6.0760	H_1	5.2545	H_0
10	1982	4.0123	H_0	5.3263	H_0	1.8430	H_0	2.0804	H_0	1.1089	H_0
11	1982	4.3955	H_0	2.4617	H_0			2.1761	H_0	5.6596	H_0
12	1982	3.2916	H_0	0.8629	H_0			1.0863	H_0	0.5250	H_0
13	1983	0.9282	H_0	5.5465	H_0	3.0380	H_0	2.0469	H_0	0.0096	H_0
14	1985	0.8108	H_0	3.3496	H_0	.		3.3853	H_0	5.4805	H_0
15	1983	1.6729	H_0	3.0442	H_0			1.8675	H_0	0.5516	H_0
16	1983	1.6468	H_0	2.3401	H_0	3.4735	H_0	3.1382	H_0	0.1341	H_0
17	1983	1.4940	H_0	0.5080	H_0	4.0937	H_0	0.4552	H_0	2.4755	H_0
18	1985	0.6904	H_0	0.5244	H_0	1.0863	H_0	5.5589	H_0	0.3158	H_0
19	1985	4.7133	H_0	6.2358	H_1	3.3142	H_0	5.7267	H_0	0.7313	H_0
20	1985	4.9449	H_0	11.9514	H_1			3.2710	H_0	6.4710	H_1
21	1983	0.8997	H_0	2.1966	H_0	3.0380	H_0	2.3004	H_0	1.4331	H_0
22	1985	1.7943	H_0	2.1327	H_0	3.0380	H_0	6.6996	H_1	3.7784	H_0
23	1984	1.3395	H_0	1.4280	H_0	2.9066	H_0	2.7795	H_0	0.4358	H_0
24	1984	4.4133	H_0	2.2594	H_0	5.5589	H_0	6.0760	H_1	1.9161	H_0
25	1983	5.0676	H_0	2.4518	H_0	2.1104	H_0			3.9643	H_0

H_0 : Accident rates at intersection for years (T-1), (T+1), (T+2), (T+3) are not different.
H_1 : Accident rates at intersection for years (T-1), (T+1), (T+2), (T+3) are different.

Rear End Accident Rates

The results of this test, which can be found in Table 9, indicate that only one of the twenty-five intersections had rear end accident rates that differed over the four years of interest. This indicates that the rear end accident rate did not change appreciably over those four years. Consequently, it appears that the all-red clearance interval did little to reduce rear end accident rates.

Right Turn Accident Rates

The results of this test, which can be found in Table 9, indicate that only four of the twenty-five intersections had right turn accident rates that differed over the four years of interest. This indicates that the right turn accident rate did not change appreciably over those four years. Consequently, it appears that the all-red clearance interval did little to reduce right turn accident rates.

Right Angle Accident Rates

The results of this test, which can be found in Table 9, indicate that only one of the twenty-five intersections had right angle accident rates that differed over the four years of interest. This indicates that the right angle accident rate did not change appreciable over those four years. Consequently, it appears that the all-red clearance interval did little to reduce right angle accident rates.

Tests in the Literature

The methodologies of three previous all-red interval studies were reproduced as faithfully as possible with the Indiana data. All three of these studies examined the before-and-after effect of the all-red interval on total accidents. As with the Student's t-tests described earlier, the before-and-after periods were defined by the calendar years on either side of the treatment year.

Newby

The result of this comparison using Indiana data contradicts the study Newby [1961] performed in England. The total number of injury accidents for the two years following the all-red interval was greater than the number for the two years prior. The eleven percent increase in accidents could be attributed to an increase in traffic volumes.

Wilson

The result of this comparison using Indiana data parallels the results Wilson [1965] obtained in Portland, Oregon. In that study, the removal of the all-red interval led to a 5.2 percent increase in total accidents within a one year before-and-after time frame. With this study, the addition of the all-red interval led to a 3.5 percent decrease in total accidents within the same time frame. This supports the common belief that the installation of the all-red clearance interval reduces accidents. Of course, it adds nothing to the information about longer-term accident rates.

Conradson and Bunker

The result of this comparison using Indiana data does not support the results Conradson and Bunker [1972] obtained in the State of Michigan.

In that study, the addition of the all-red interval led to a statistically significant (10 percent) decrease in total accidents within a one-year before-and-after time frame. With the Indiana data from this study, the addition of the all-red interval led to a statistically insignificant (3.5 percent) decrease in total accidents within the same time frame. The statistical tests that could affirm that the all-red interval reduces accident rates fail to do so.

CHAPTER 5 - CONCLUSIONS

Summary of Results

The primary purpose of this research was to estimate the short-term and long-term accident rate reduction effects of the all-red clearance interval on accident rates in Indiana. The tasks completed were a literature review, graphical and statistical analyses of accident rate data, and a comparison of results using methods from prior studies. From this work, information related to the all-red clearance interval has been increased, but there are still facets of this issue which need to be explored.

The significant results of the research are listed in the following paragraphs. First, the literature review indicated, among other things, that:

1. The addition of the all-red clearance interval to the signal cycle has been shown in several, but not all, previous studies to reduce accidents in the first year after its introduction.
2. The majority of the accident reduction occurs with right-angle accidents, while left-turn accident figures remain unchanged.
3. Accident rates were not used as a measure of effectiveness for all-red interval studies until about 1980.

The graphical analysis of the accident rates showed that no clear cut conclusion could be made on the basis of those figures alone. Depending on the interpretation of the graph, accident rates either went up or down after the all-red interval implementation.

The statistical analysis of the accident rates showed that:

1. Using the Wilcoxon Signed Rank test produced few statistically significant differences between the treated and the comparison groups. This indicates that the all-red interval did not reduce accident rates significantly when compared to intersections that lacked the all-red interval.
2. With the Student's t-test, the only statistically significant difference was found with right angle accident rates at treated intersections for the period one-year before the all-red interval implementation and one-year after. All other tests yielded no difference. This indicates that accident rates did not decrease significantly after the implementation of the all-red interval.
3. With the Chi-Square test, few statistically significant differences were found at treated intersections. Thus, for the years analyzed before and after the all-red interval was added, no significant accident rate reduction took place.

Finally, comparison with other studies using Indiana data showed that:

1. The addition of the all-red interval failed to reduce injury accidents over a two year before-and-after period.
2. The all-red interval reduced total accidents over a one-year before-and-after period, but not significantly. This supports one previous study and refutes another.
3. Results contrary to the original studies may be partially

attributed to the use of accidents in the original studies instead of accident rates as the indicator of safety.

Conclusions

The results from this project should be used carefully to substantiate or refute sweeping statements concerning the all-red clearance interval. The confinement of the study area to Indiana and to a relatively small number of intersections cautions against generalizing the results beyond the scope of work performed. These results by themselves should not be used as justification to remove the all-red clearance interval from the signal cycle. They do, however, serve as a caution against implementing the all-red interval with the assumption that it will reduce accidents.

Drivers may be adjusting to the all-red interval as its occurrence becomes more common place. Once the newness of the phase has worn off, drivers may be adjusting their behavior to "extend" the yellow clearance interval into the all-red interval. As a result, the decrease in accidents may be of a very short-term nature. Consequently, the utility of the all-red interval as a clearance interval has been severely compromised.

Several factors could have degraded the accuracy of the results. Bias was unwittingly introduced into the sample by the engineers who decided which intersections received the all-red interval. Not all accidents may have been reported or coded properly. The uniform growth factors used to grow the traffic volumes may not have been appropriate. Although the Wilcoxon Signed Rank test and the Student t-test were powerful, perfectly appropriate statistical tests, they only detected large effects. The interaction of these factors introduced a certain amount of "fuzziness" into any conclusions drawn from this research.

Future Work

Several facets of the all-red clearance interval topic require further study. The methods necessary to conduct such research include additional experimental control, data collection, and procedures. Continuous effort over several years is required to do justice to the complexity of the issue.

Any subsequent study should attempt to include more sites than this study. The installation of the all-red interval should be a pre-meditated event, not an after-the fact observation. Coupled with the collection of additional data cited in Chapter Three, this experimental control will establish greater credibility of results.

Additional procedures could be incorporated into future studies to delve into further all-red interval topics. Intersection operations could be videotaped to monitor driver behavior and compliance. Turning movement counts performed periodically could calibrate the volume adjustment factors. Coupled with the aforementioned videotape, an assessment of the tradeoff between safety and delay could be performed. Other statistical techniques such as the Negative Binomial or the Empirical Bayesian could cast the results in a new light. Ultimately, guidelines for the use of the all-red clearance interval could be assembled.

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